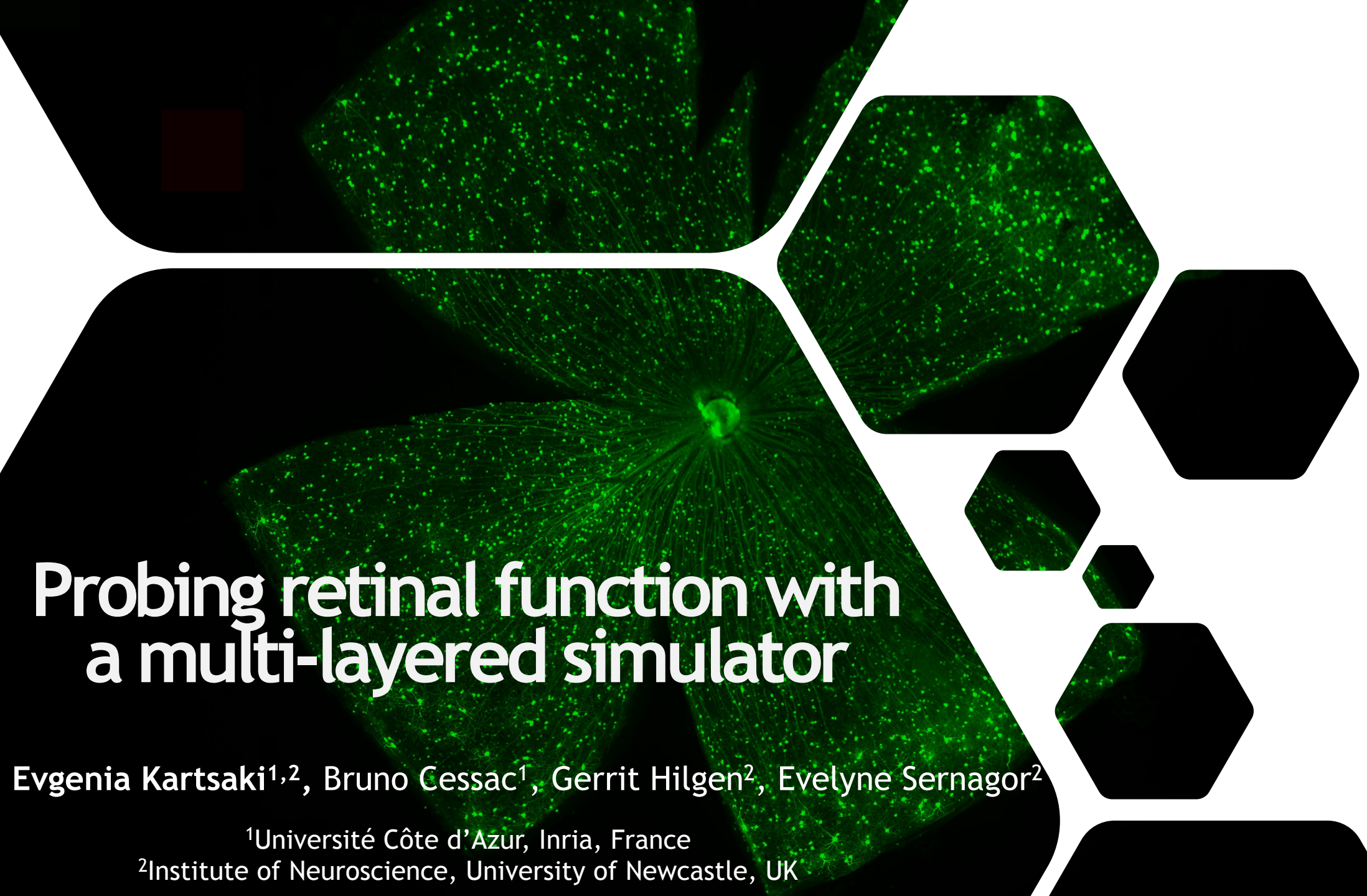
Probing retinal function with a multi-layered simulator

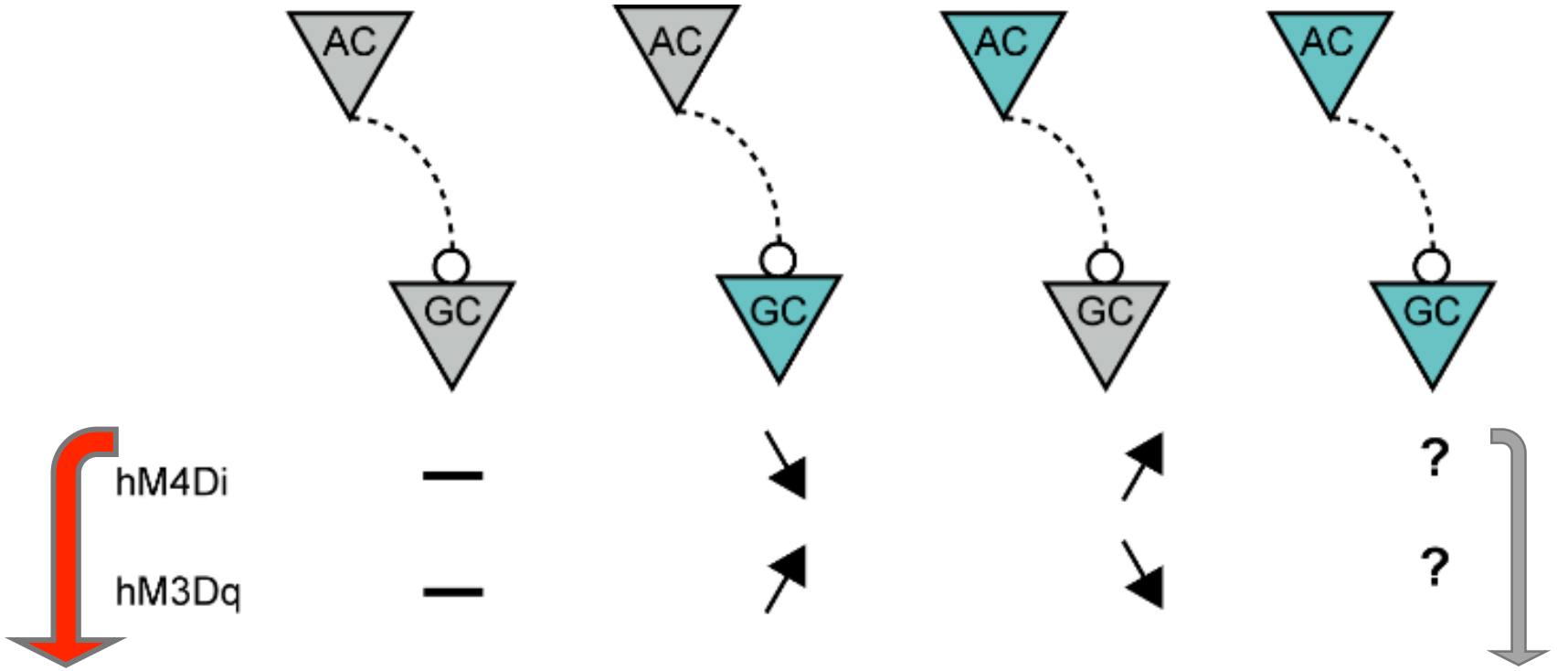
Evgenia Kartsaki, Bruno Cessac, Gerrit Hilgen, Evelyne Sernagor



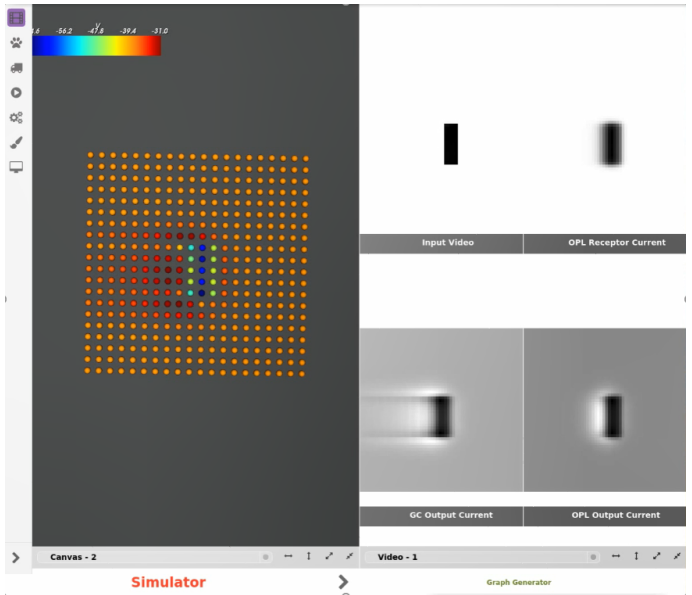
Probing retinal function with a multi-layered simulator

Evgenia Kartsaki[1,2], Bruno Cessac[1], Gerrit Hilgen[2], Evelyne Sernagor[2]

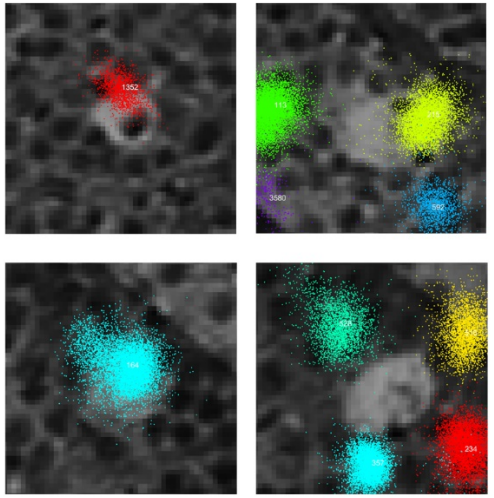
[1]Université Côte d'Azur, Inria, France
[2]Institute of Neuroscience, University of Newcastle, UK



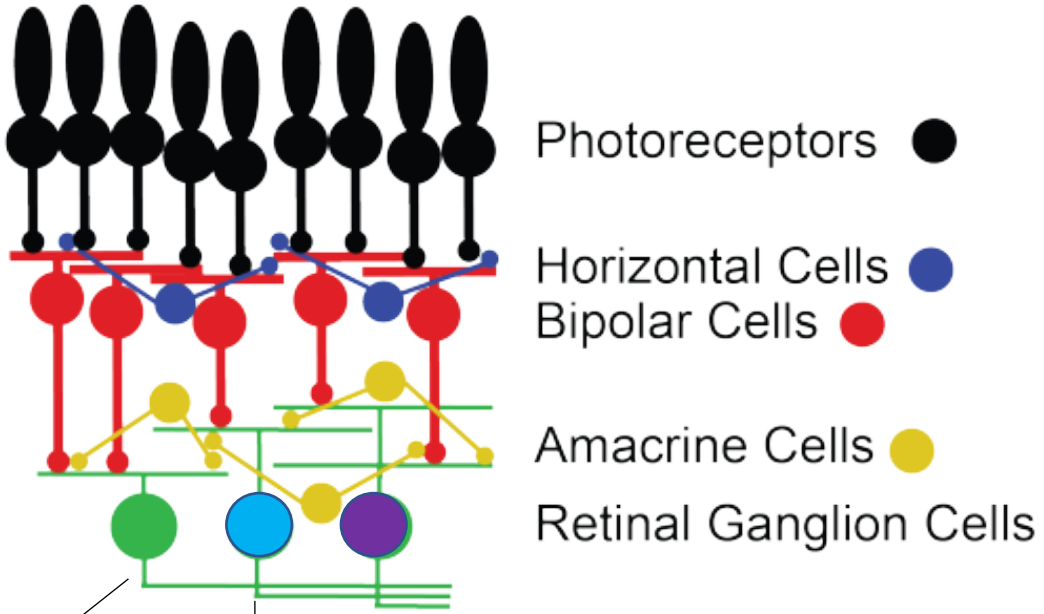
Retinal Simulator



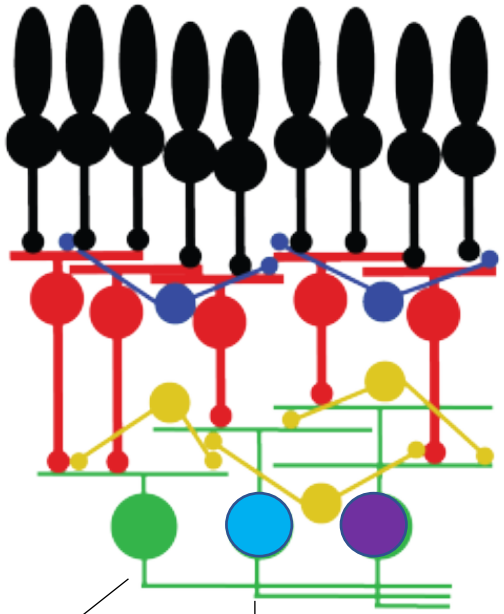
Electrophysiology & IHC



Gerrit Hilgen

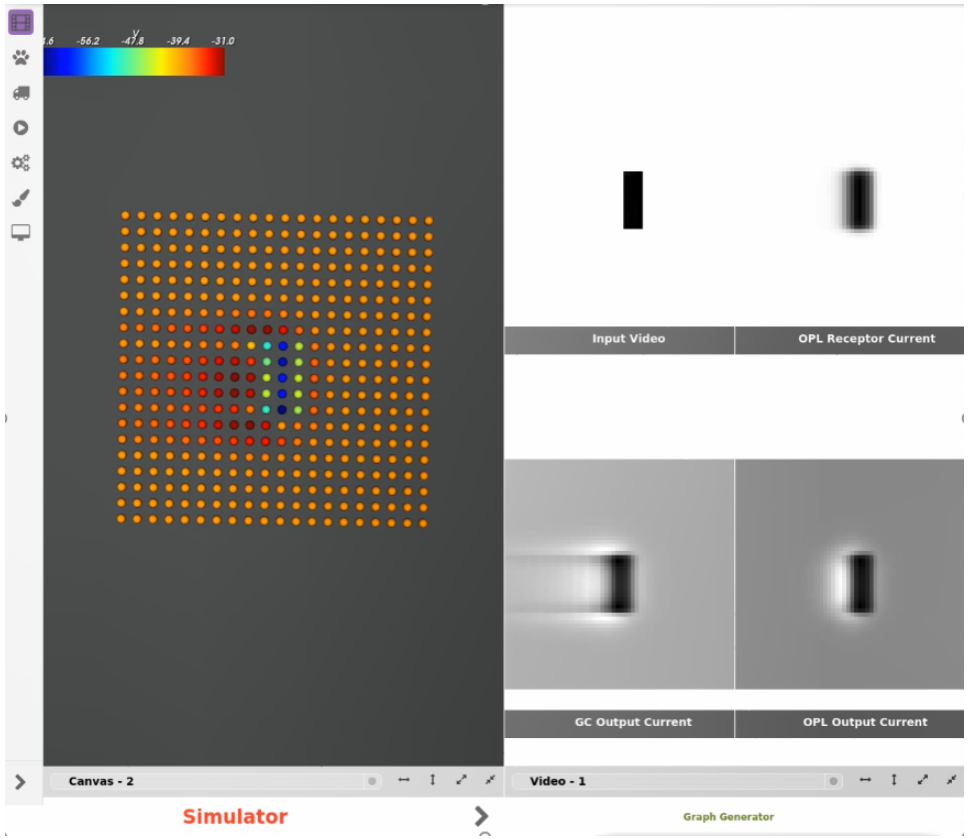


Source: ETH Zürich & RavaAzeredo da Silveira et al., 2011



$$\frac{dy}{dx}$$

Macular



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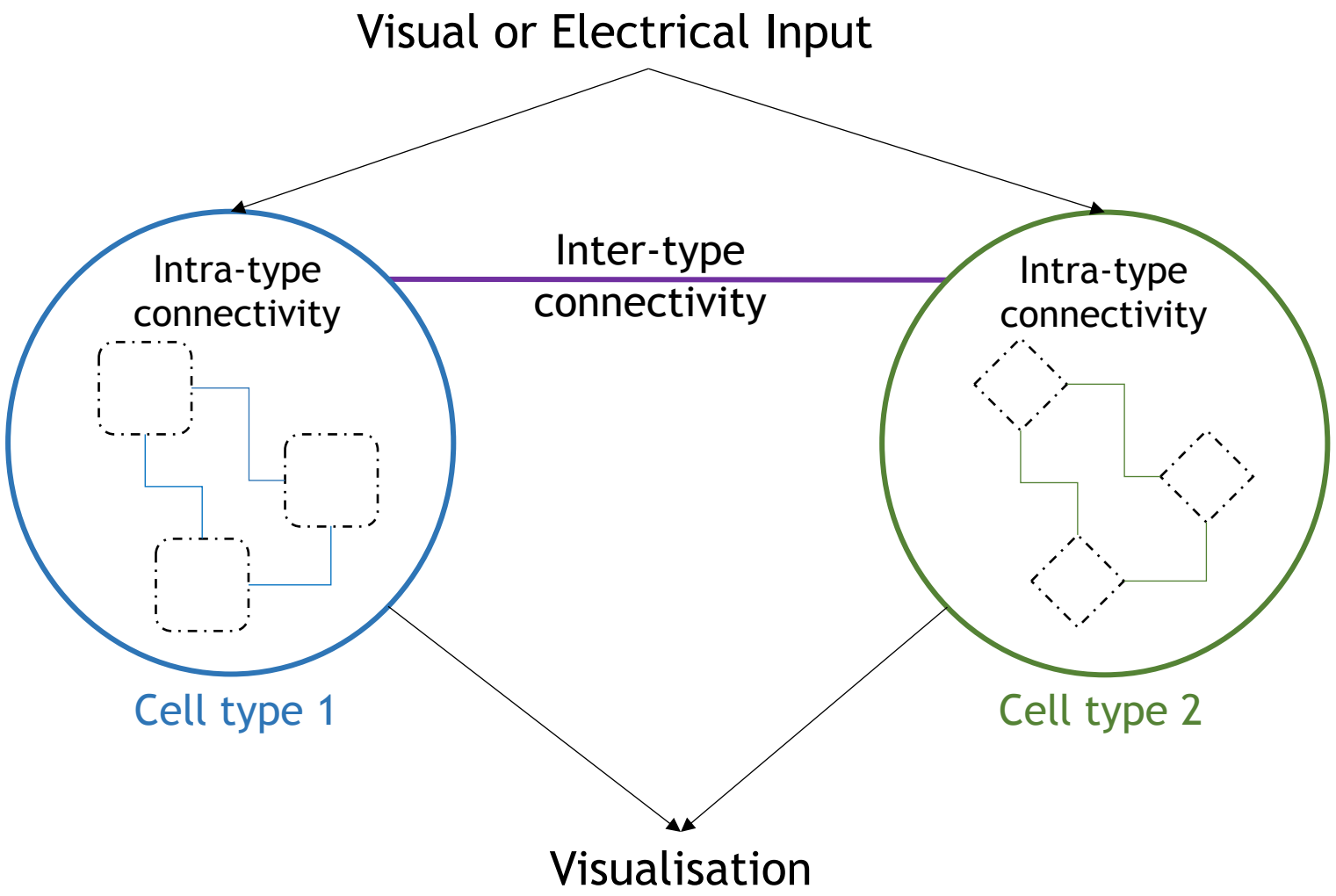
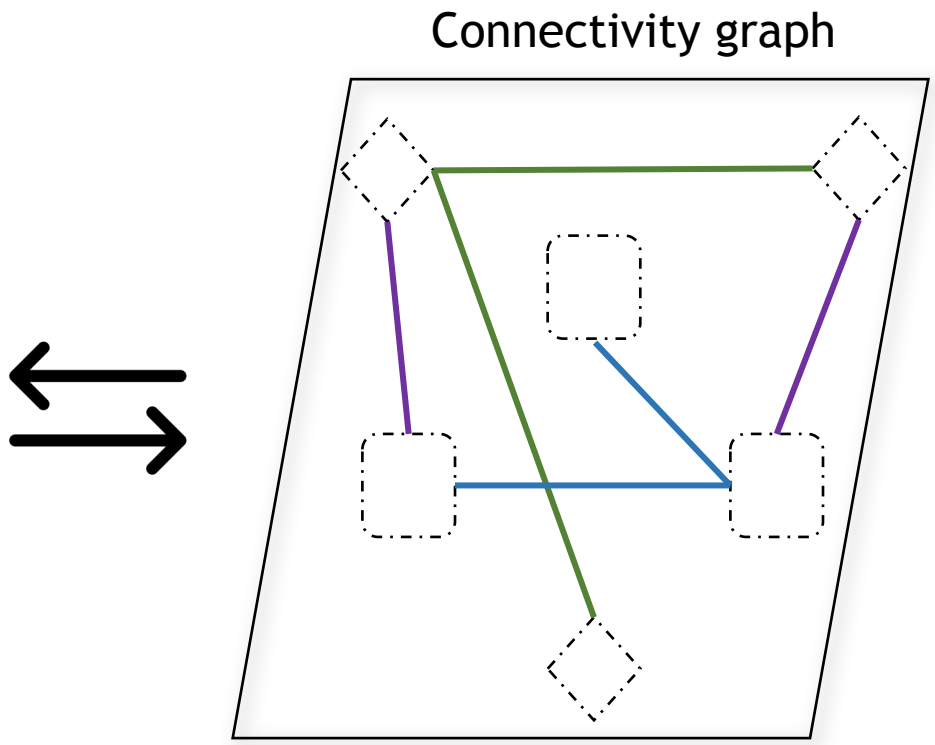
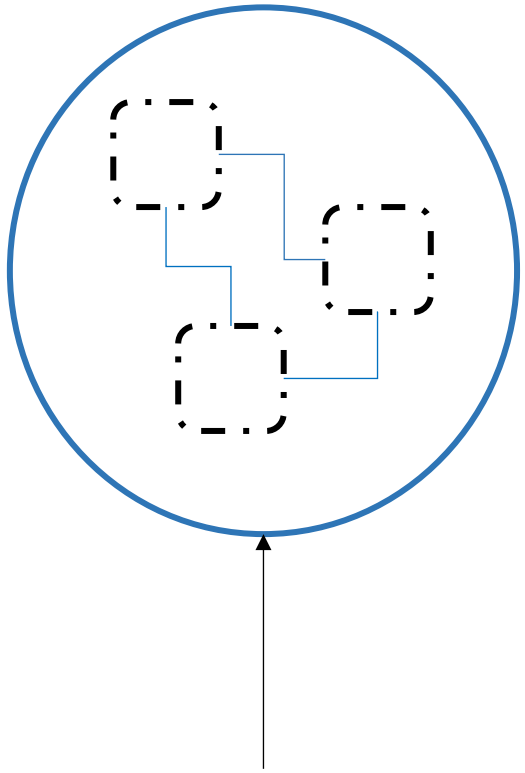
General structure



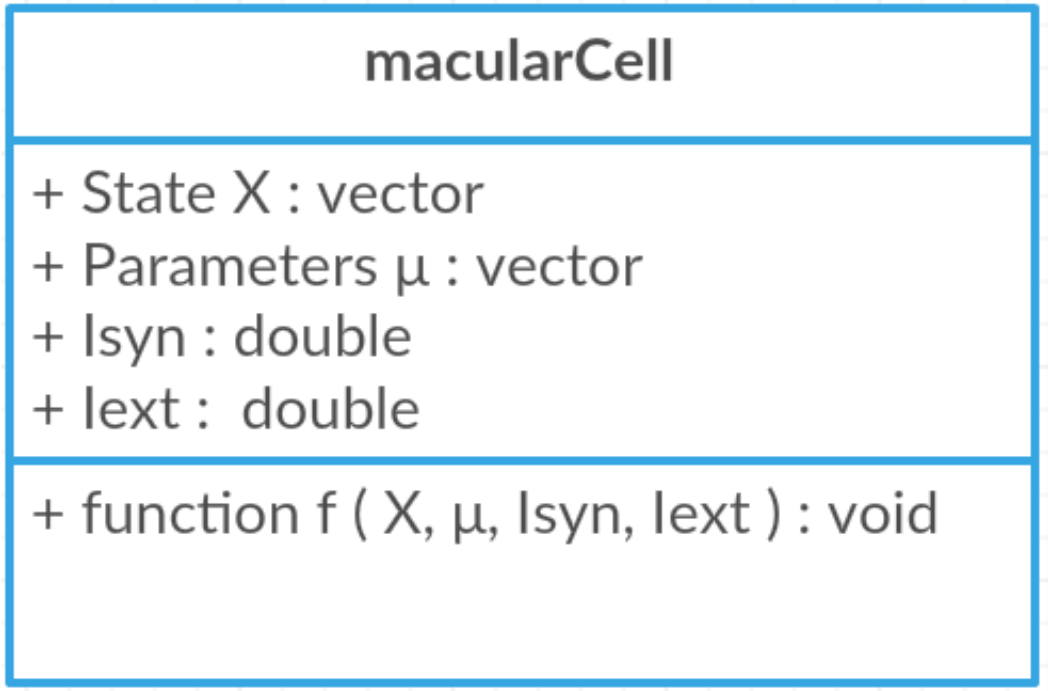


Basic building blocks - cell



Cell

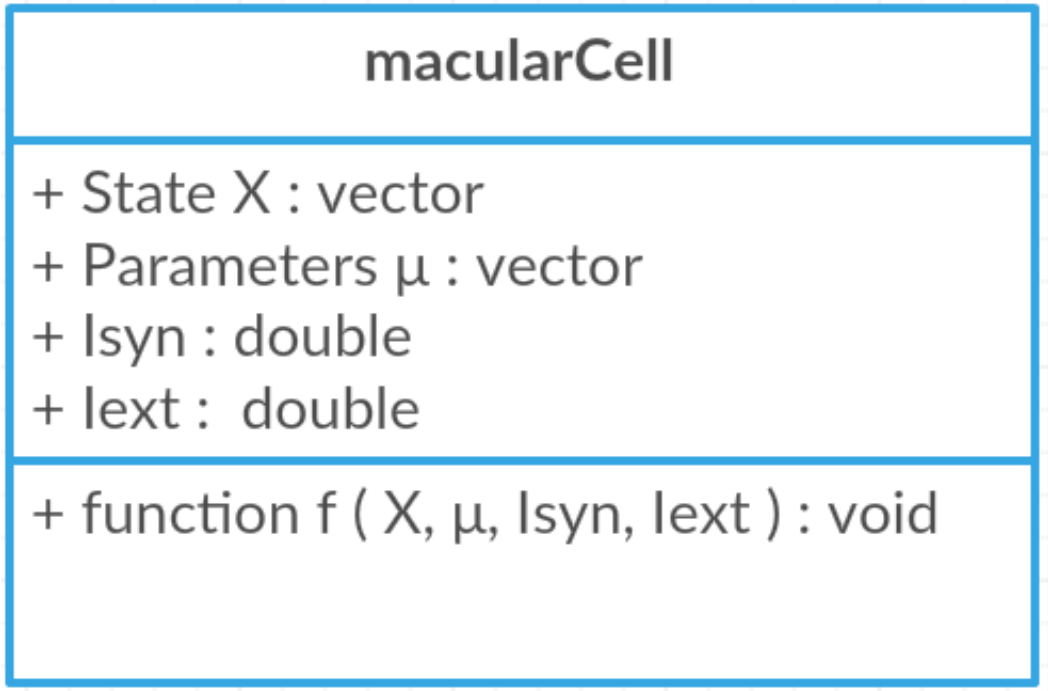
- ✓ A set of **variables** evolving in time and characterizing the cell's evolution : e.g. membrane potential, probability that a ionic channel of a given type is open etc.



Cell

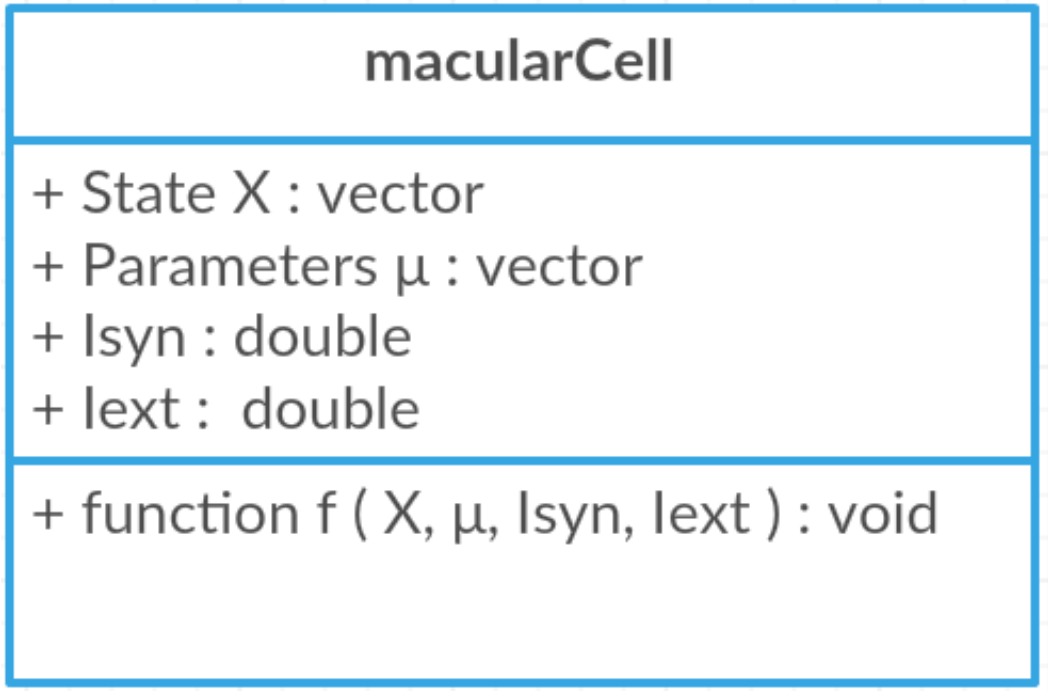
- ✓ A set of **variables** evolving in time and characterizing the cell's evolution : e.g. membrane potential, probability that a ionic channel of a given type is open etc.

- ✓ A set of **parameters** that constrain the cell's evolution : e.g. conductance, reversal potential, membrane capacitance, characteristic time of a channel's activity



Cell

- ✓ A set of **variables** evolving in time and characterizing the cell's evolution : e.g. membrane potential, probability that a ionic channel of a given type is open etc.
- ✓ A set of **parameters** that constrain the cell's evolution : e.g. conductance, reversal potential, membrane capacitance, characteristic time of a channel's activity
- ✓ A function controlling the cell's evolution with a differential equation



Cell

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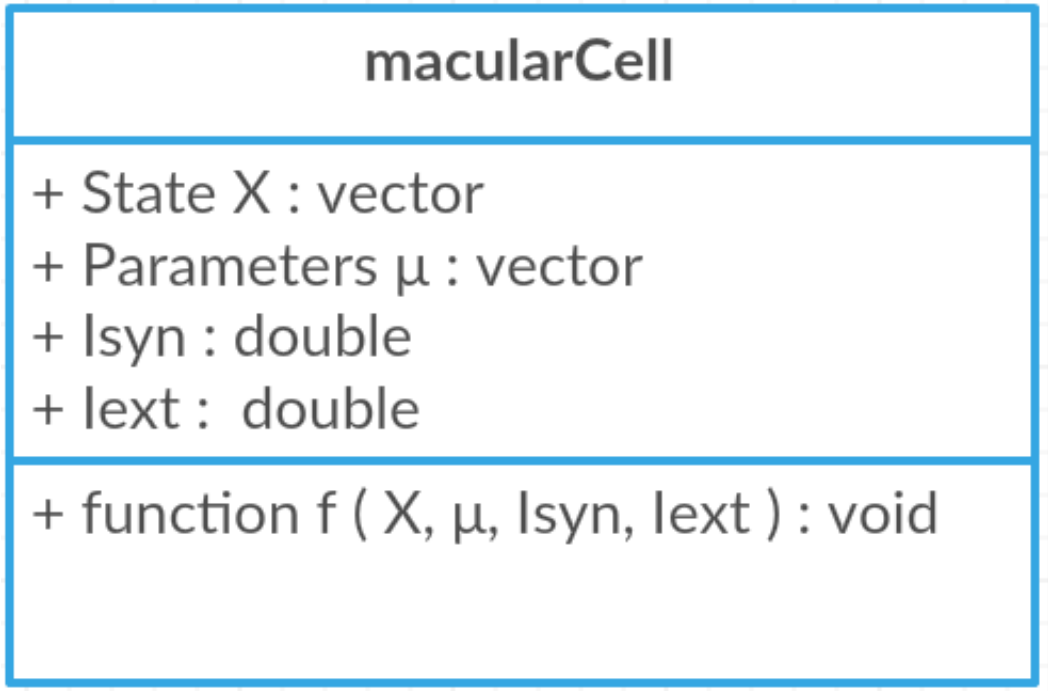
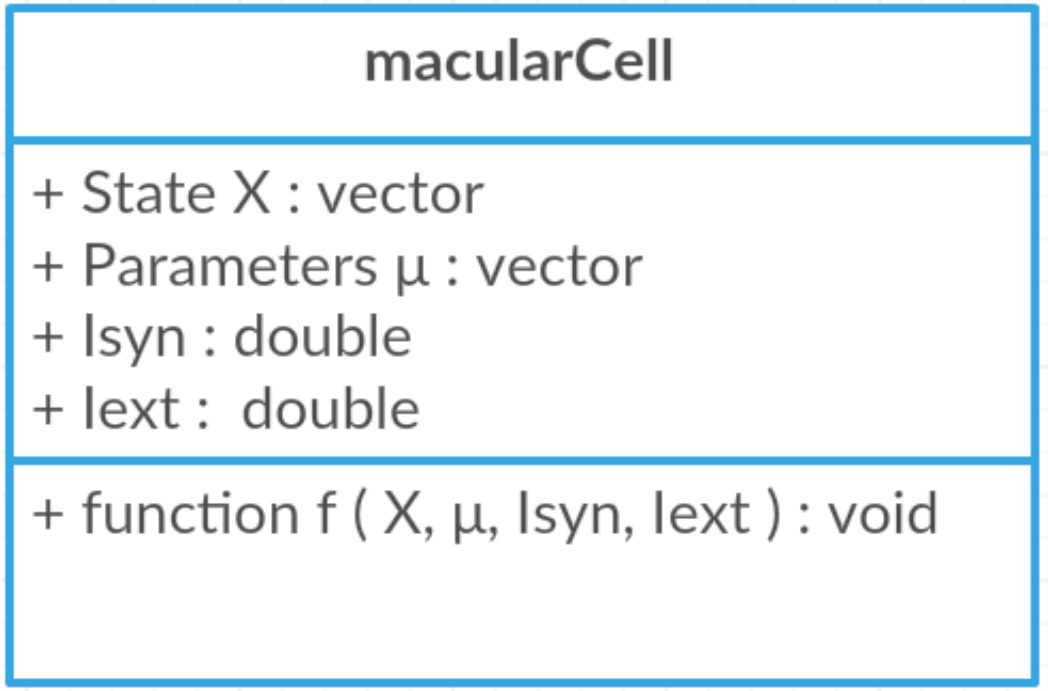
- ✓ A function controlling the cell's evolution
- ✓ **Isyn :** A synaptic input corresponding to synaptic connections with other cells

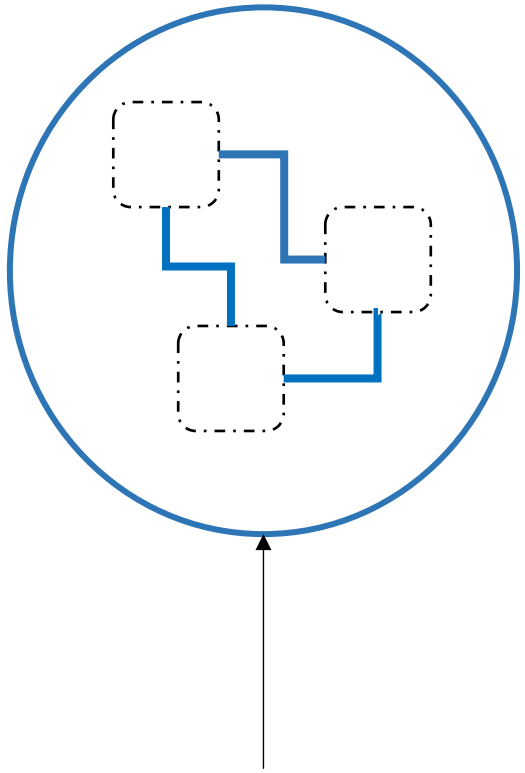


Cell

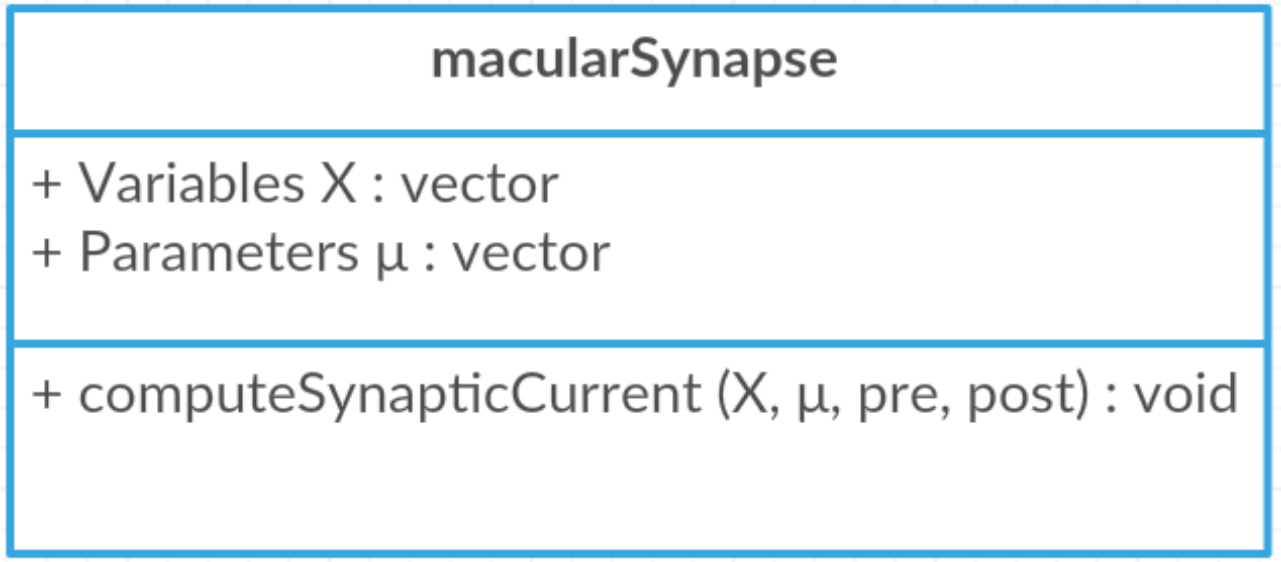
- ✓ A set of **variables** evolving in time and characterizing the cell's evolution : e.g. membrane potential, probability that a ionic channel of a given type is open etc.
- ✓ A set of **parameters** that constrain the cell's evolution : e.g. conductance, reversal potential, membrane capacitance, characteristic time of a channel's activity
- ✓ A function controlling the cell's evolution
- ✓ **Isyn** : A synaptic input corresponding to synaptic connections with other cells
- ✓ **Iext** : An external input corresponding either to a visual input or the electric current provided by an electrode



Basic building blocks - synapse

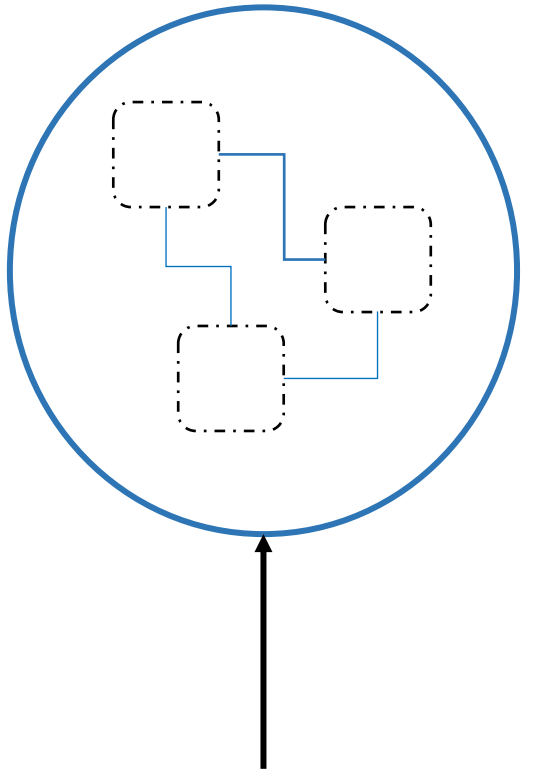


Synapse



- ✓ Chemical or electrical (gap junction)
- ✓ A set of variables that evolve in time : e.g. conductance
- ✓ A set of parameters : e.g. synaptic weight

Basic building blocks – External Input



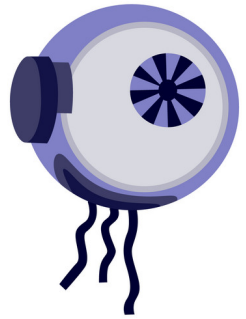
External Input

Visual Input

Virtual Retina module

- ✓ Emulate the outer plexiform layer (OPL) current

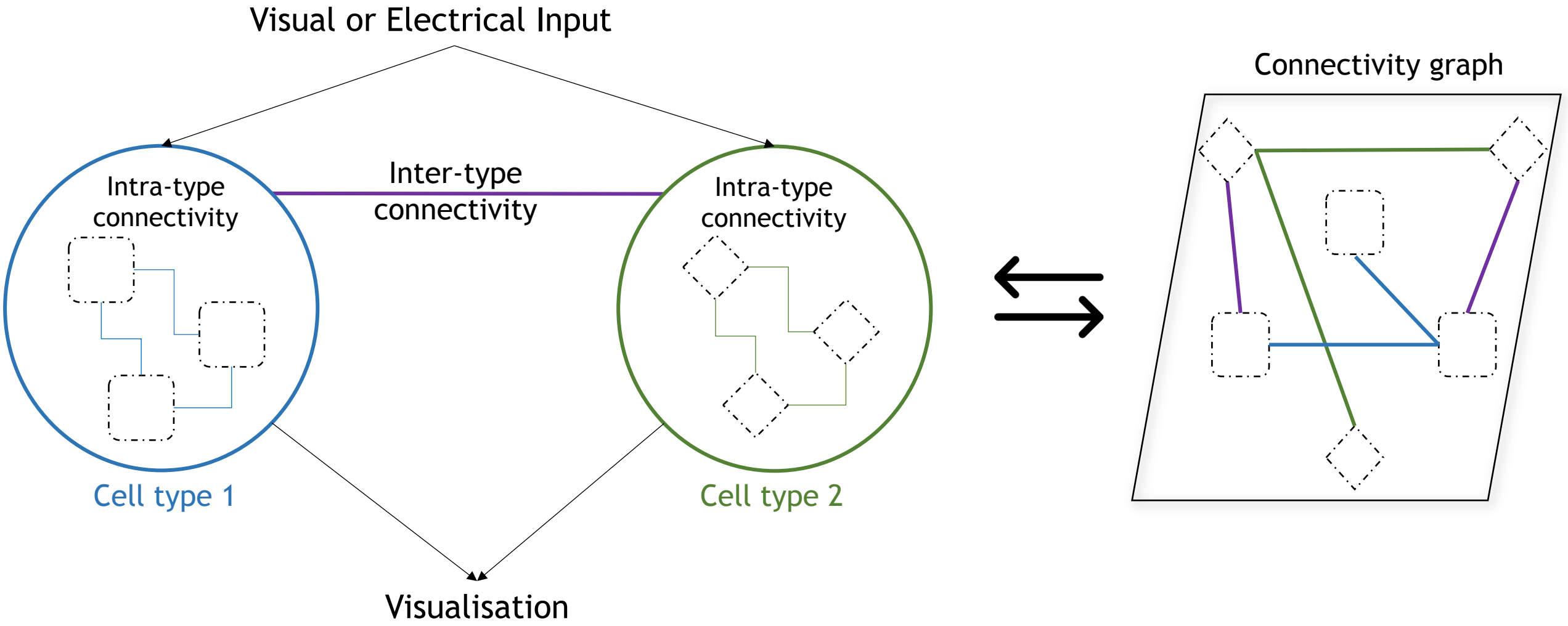
A.Wohrer et al., 2009



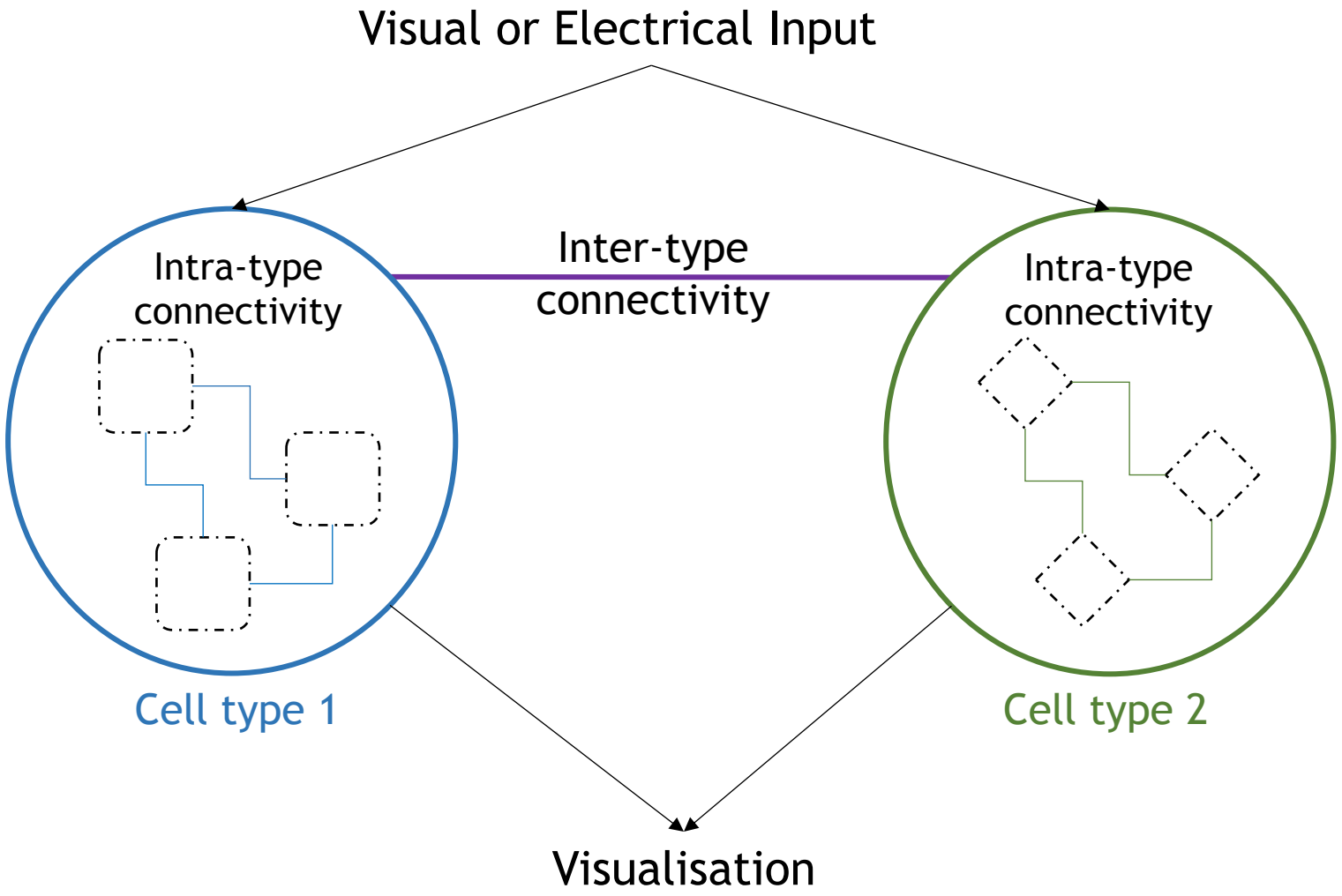
Retinal prosthesis

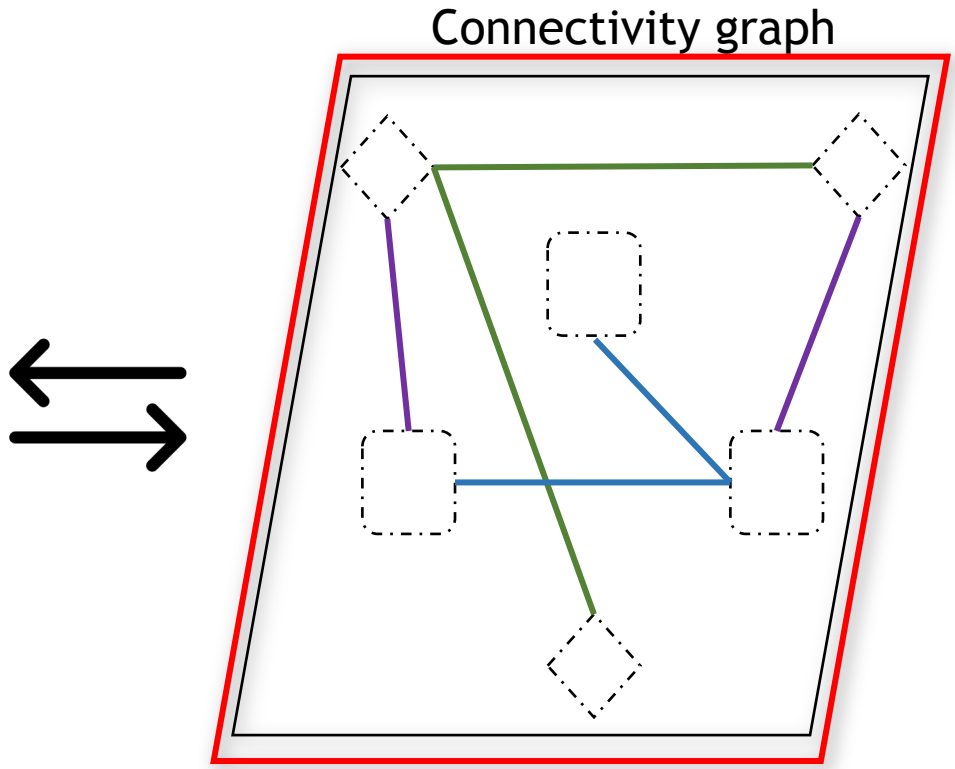
- ✓ Emulate the electric current provided by an electrode

General structure

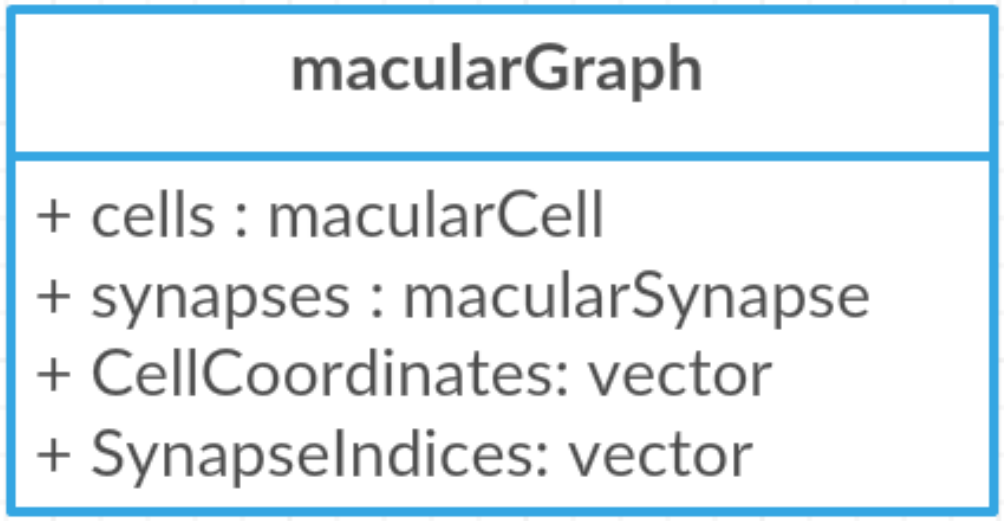


General structure



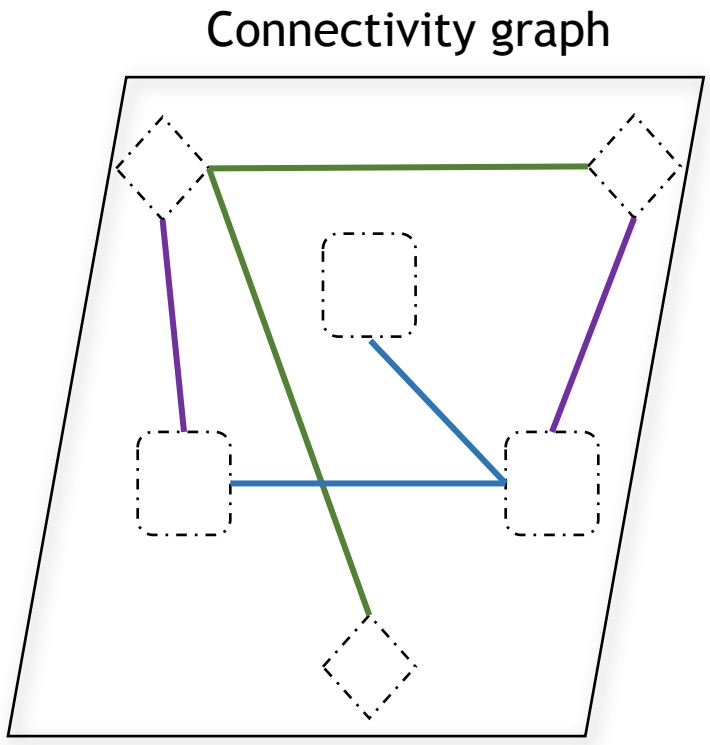


Graph

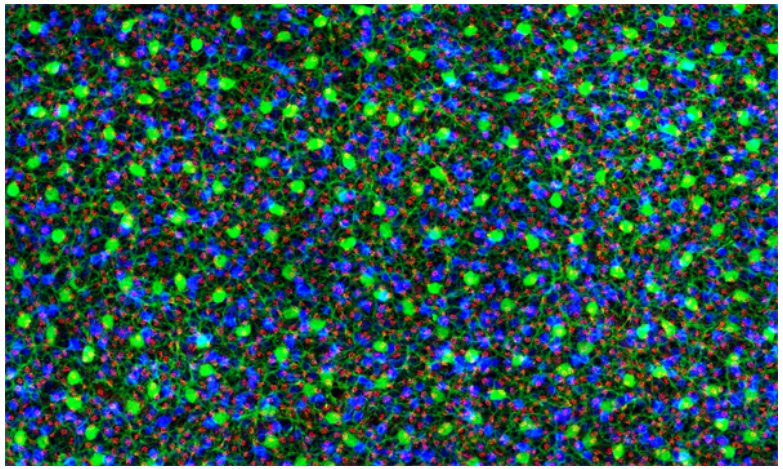


- ✓ Cell types
- ✓ Synapse types
- ✓ Cell coordinates
- ✓ Synapse indices

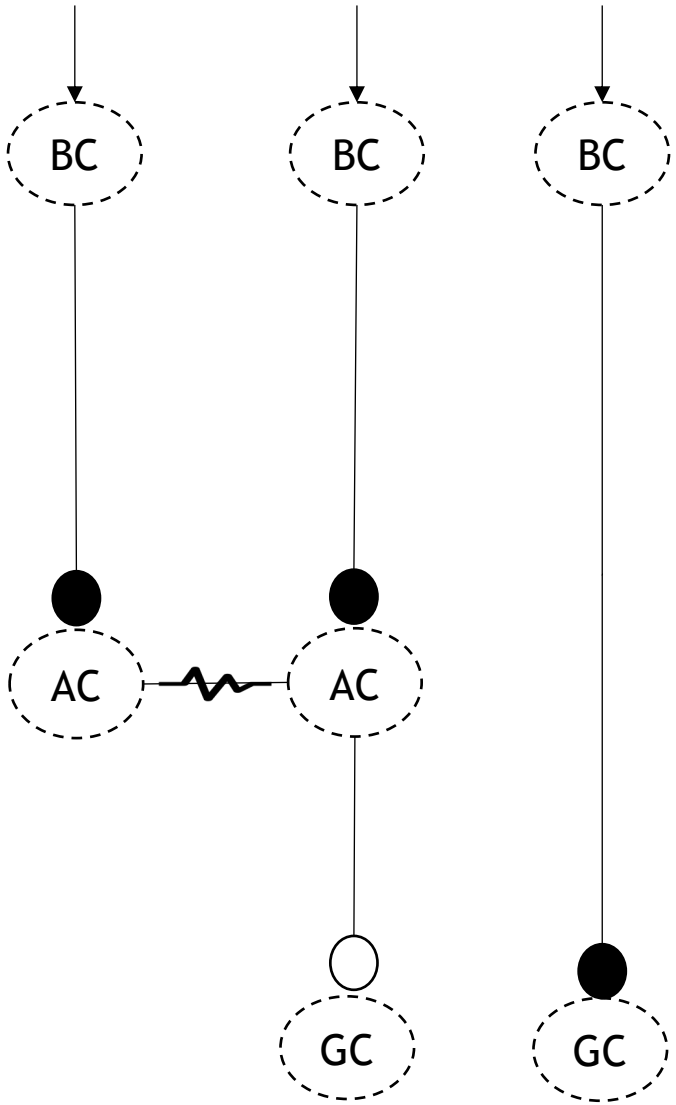
Graph

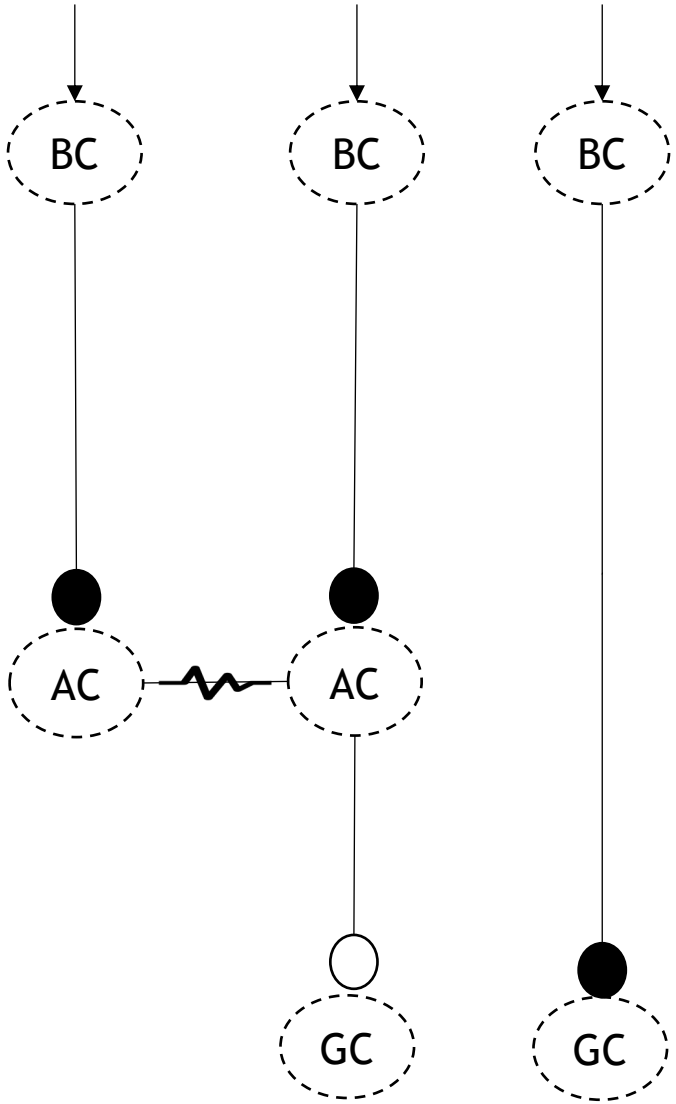


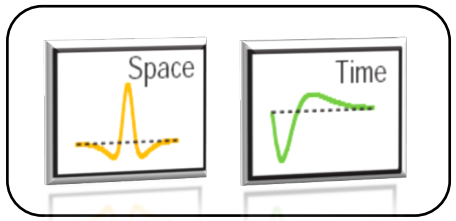
- ☞ Design a local circuit with specific connectivity patterns
- ☞ Deploy it to the whole retina



Source: *From Gabriel Luna, Steve Fisher and Geoff Lewis, retinal cell biology group at UC Santa Barbara Neuroscience Research Institute*

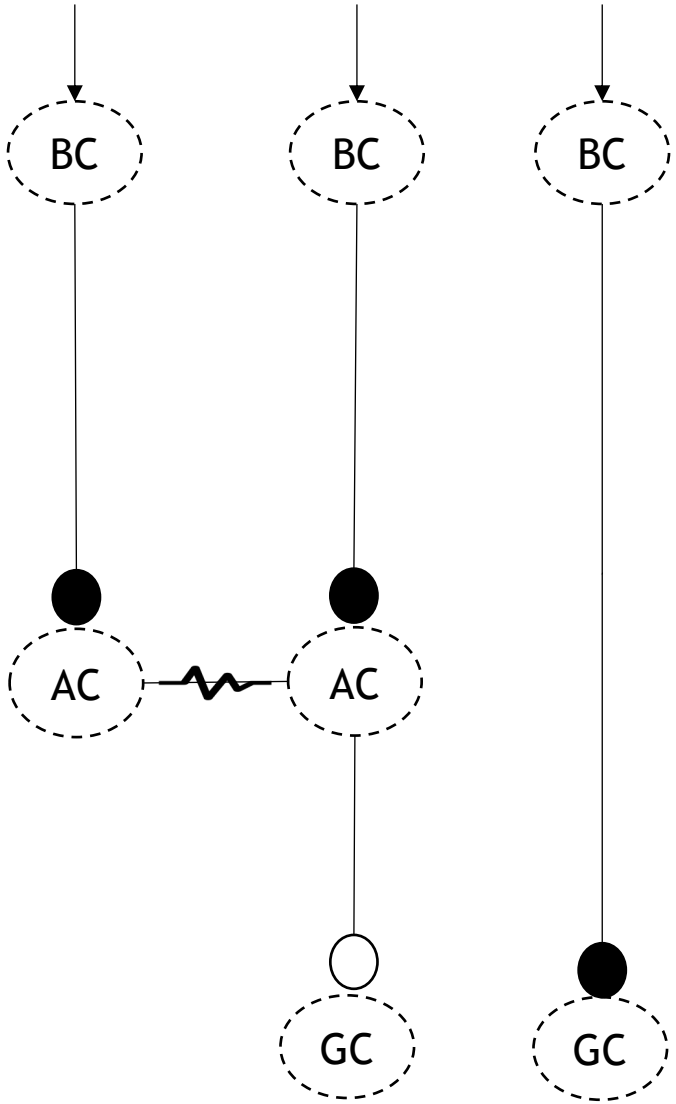

BC
BC
BC
AC
AC
GC
GC
Chemical synapse
Electrical synapse

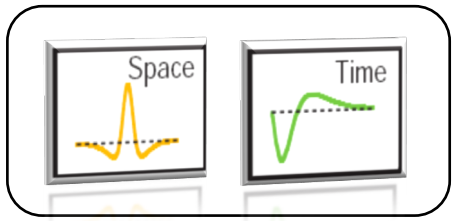




$$K(x, y, t) = K_S(x, y)K_T(t)$$

$$\int (S * \mathrm{K})(\mathrm{x,y,t})$$





Chemical synapse

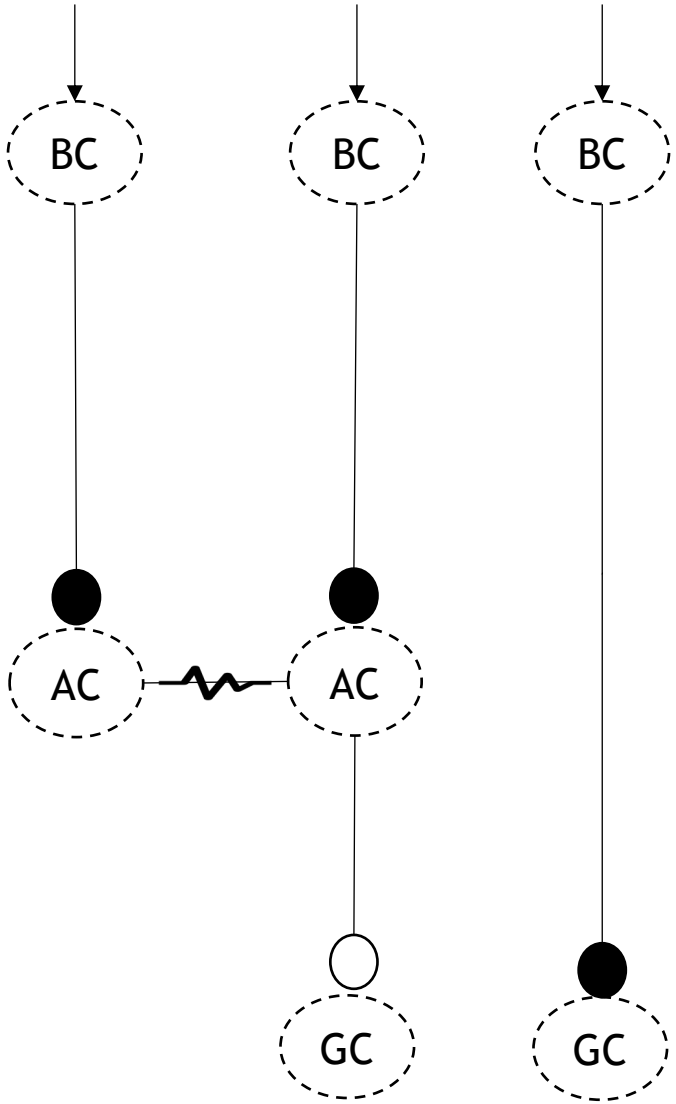
Electrical synapse

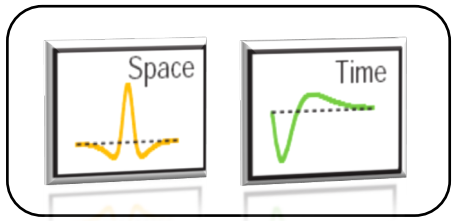
$$K(x,y,t) = K_S(x,y)K_T(t)$$

$$\int (S * \mathrm{K})(\mathrm{x,y,t})$$

$$I_{syn} = -g_{syn}\left(V_{post} - E_{syn}\right)$$

$$I_{GAP} = -g_{GAP}\left(V_{post} - V_{pre}\right)$$





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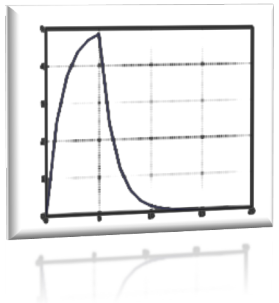
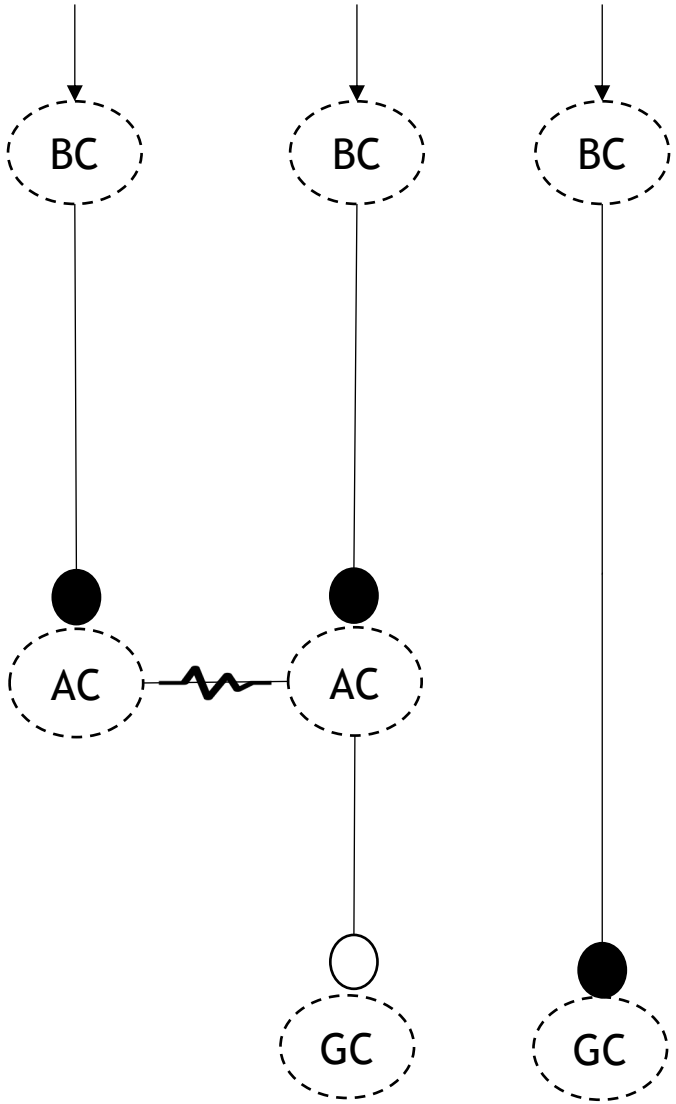
$$\int (S * \mathrm{K})(\mathrm{x,y,t})$$

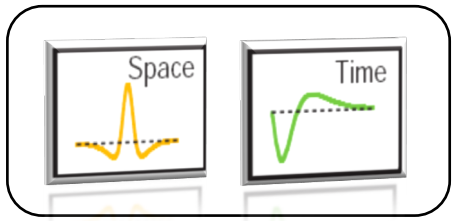


$$I_{syn} = -g_{syn}\left(V_{post} - E_{syn}\right)$$

$$I_{GAP} = -g_{GAP}\left(V_{post} - V_{pre}\right)$$

$$C\frac{dV}{dt} = -g_L(V - V_L) + Isyn + Iext + I_{CNO}$$





$$K(x,y,t) = K_S(x,y)K_T(t)$$

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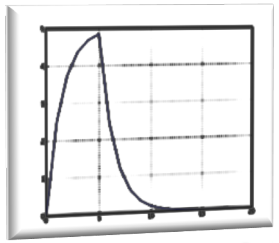
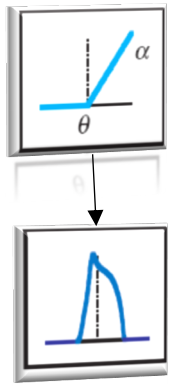
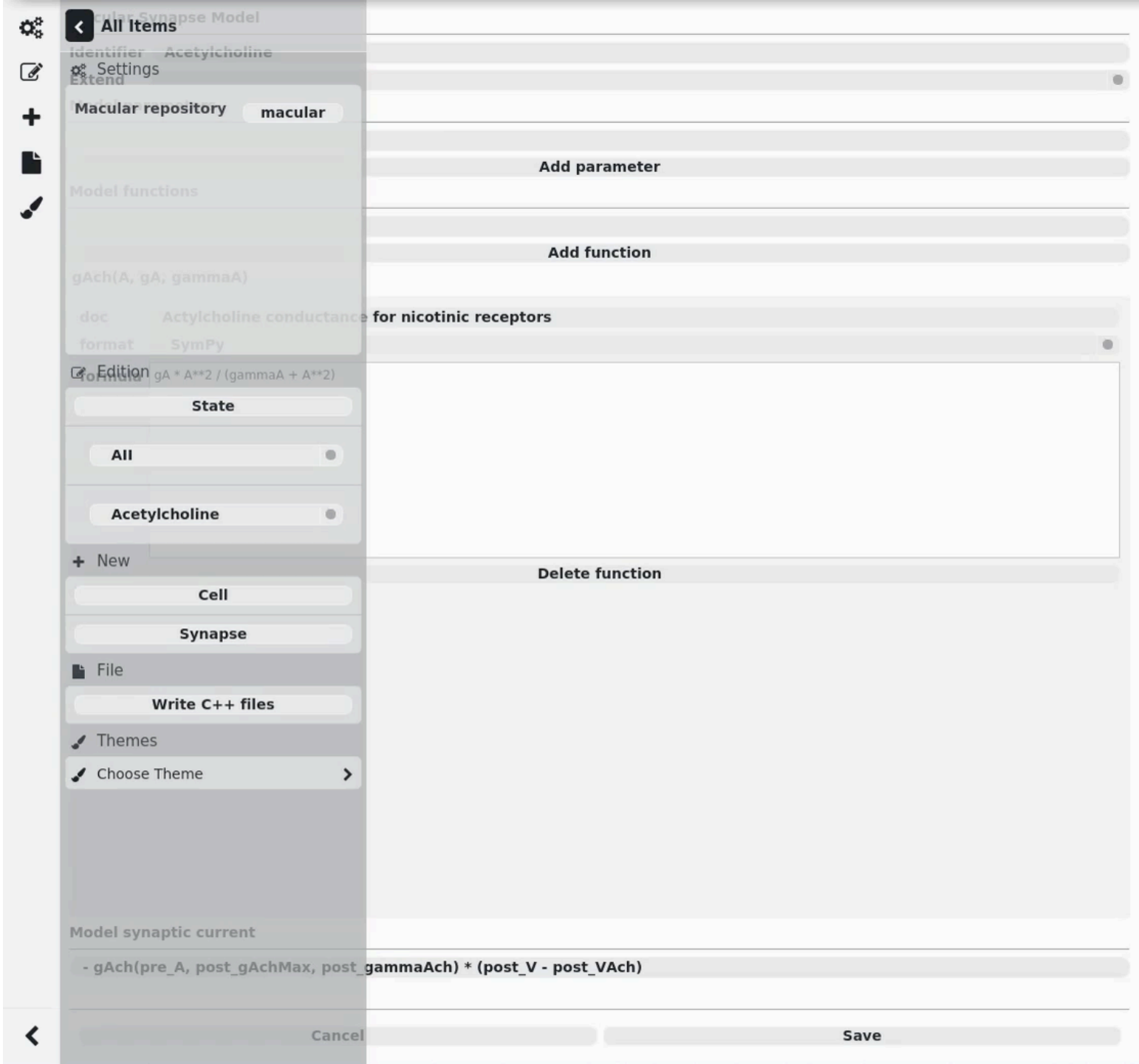




$$C\frac{dV}{dt} = -g_L(V - V_L) + Isyn + Iext + I_{CNO}$$

$$N_G(V) = \begin{cases} 0, & if(V \le 0) \\ \alpha(V-\theta), & if(\theta \le V \le \dfrac{N_{max}}{\alpha+\theta} \\ N_{max}, & otherwise \end{cases}$$

Chen et al., Journal of Neuroscience 2 January 2013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macular
Edition
State
All
Acetylcholine
New
Cell
Synapse
File
Write C++ files
Themes
Choose Theme
Add parameter
Add function
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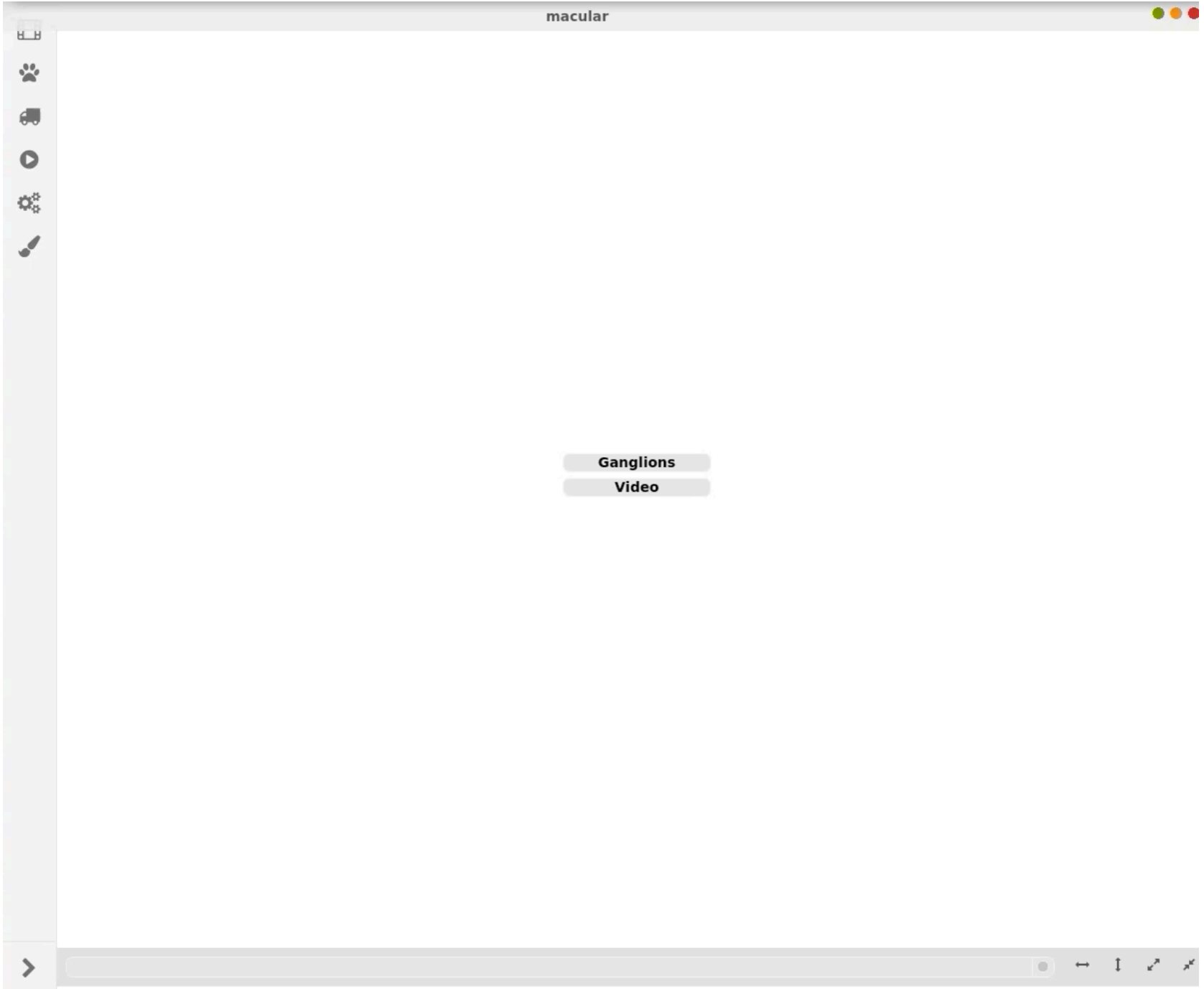
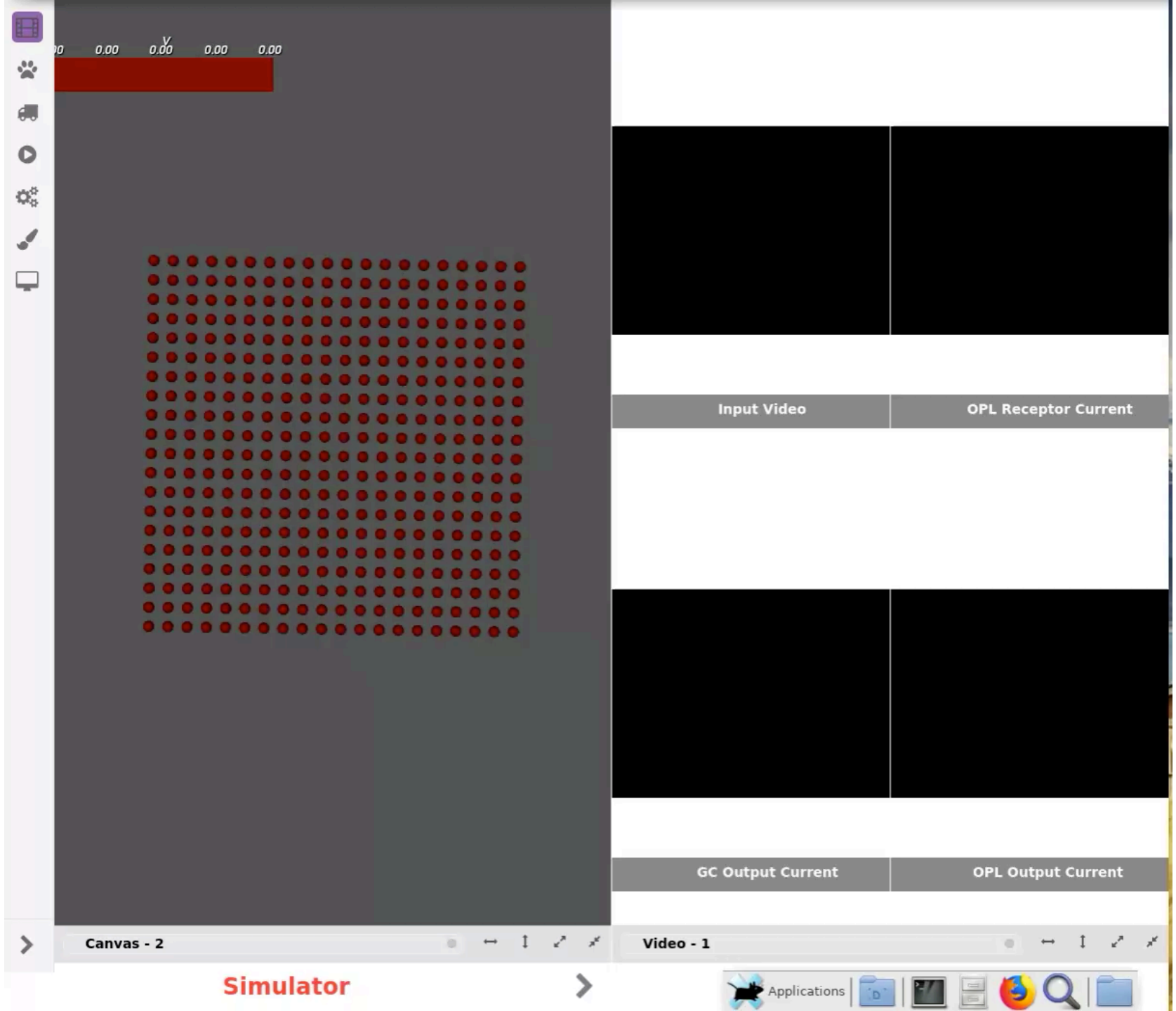
for nicotinic receptors
Model synaptic current
- gAch(pre_A, post_gAchMax, post_gammaAch) * (post_V - post_VAch)
Cancel
Save



Simulator

Graph Generator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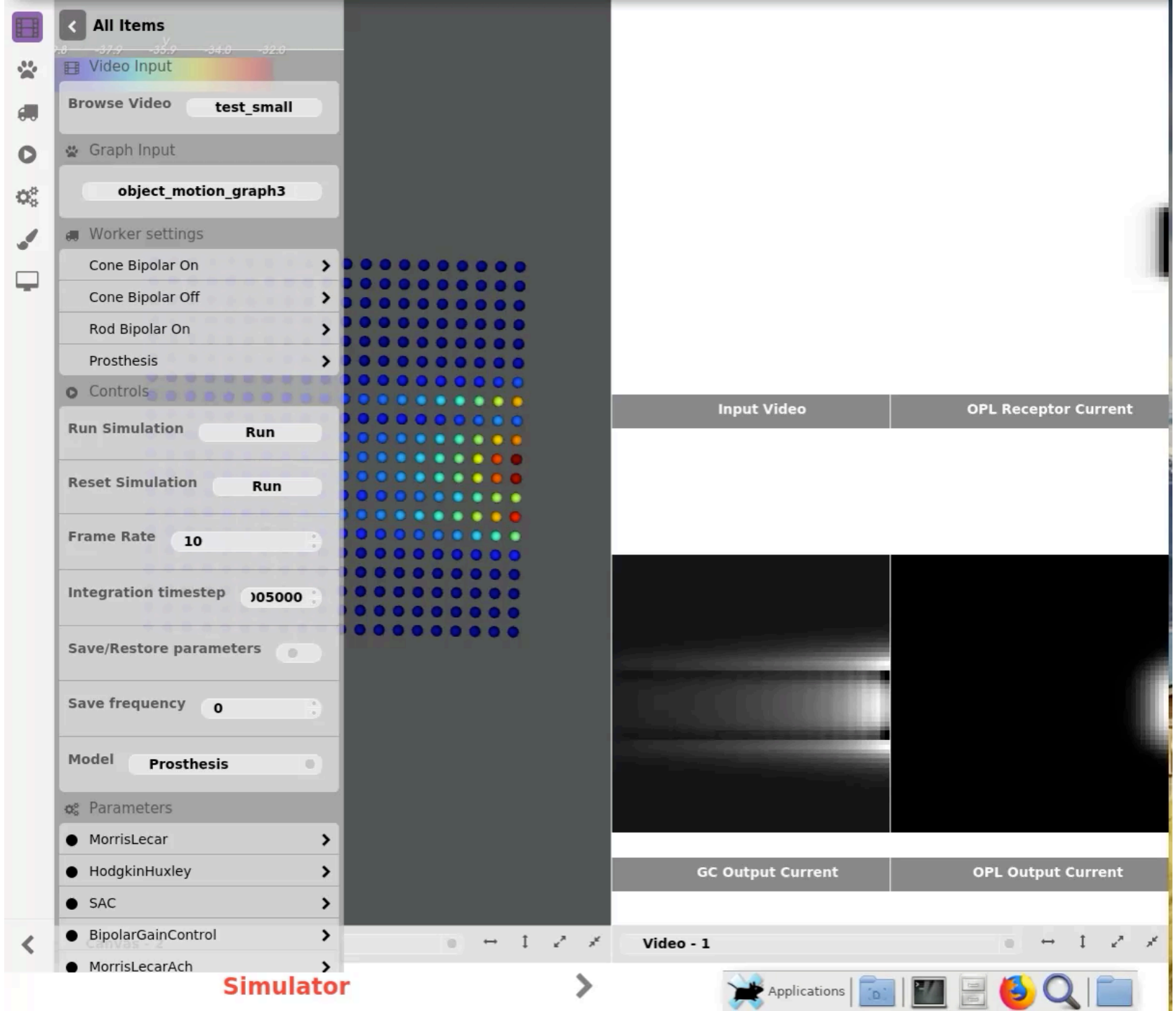
Input Video
OPL Receptor Current
GC Output Current
OPL Output Current
Canvas - 2
Video - 1
Simulator
Applications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Graph Input
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Cone Bipolar Off
Rod Bipolar On
Prosthesis
Controls
Run Simulation
Run
Reset Simulation
Run
Frame Rate
10
Integration timestep
Save/Restore parameters
Save frequency
0
Model
Prosthesis
Parameters
MorrisLecar
HodgkinHuxley
SAC
BipolarGainControl
MorrisLecarAch
Input Video
OPL Receptor Current
GC Output Current
OPL Output Current
Video - 1
Applications

Simulator

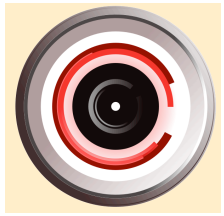
Acknowledgements

Prof. Evelyne Sernagor
Dr. Gerrit Hilgen

Newcastle University
Institute of Neuroscience

Biovision team

Dr. Bruno Cessac
AMDT team



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Thank you!

Questions?